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AN EXPERIMENTATION INTO THE UTILIZATION OF DIFFERENT DYE ABSORPTION MATERIALS, DYE SENSITIZERS AND ELECTROLYTE MEDIUM IN A DYE SENSITIZED SOLAR CELL

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ABSTRACT

The stronger thrust on the use of renewable energy by phasing out the dependence on fossil fuels has led to an intensive research in the field of solar photovoltaics with much emphasis on materials and methods that could greatly bring down the cost of solar cells through the incorporation of suitable technologies involving greener materials that are believed to be both nature and pocket friendly. Dye sensitized solar cells are a fast emerging technology trend in the field of utilization of the ever shining bundle of enormous green energy, sun. Recent advances in the field of material science have enabled these cells to compete against the traditional silicon solar cells. The present paper discusses the effect of utilization of the oxides of various other D-group elements in the periodic table such as Manganese Chromium, and the most commonly used Titanium, as the material for the absorption of the dye. The paper also compares the performance of three different natural dyes derived out of spinach, grape and pomegranate. The current work also evaluates the performance of the cell under the application of both solid and liquid electrolyte in the form of fused salt and iodide electrolytes respectively. The fabricated dye sensitized solar cells are grouped and coded for easy recognition and are exposed to sunlight for a particular length of time. The voltage generated is measured with the help of a calibrated multimeter. The results indicate that manganese dioxide used for dye absorption performs at par with titanium dioxide, while chromium trioxide fails miserably in this regard. Also, dark colored dyes generated higher voltage in comparison with light colored dye.

***KEYWORDS:** Dye Sensitized Solar Cells, Titanium Dioxide, Manganese Dioxide, Chromium Trioxide, Spinach Dye, Grape Dye & Pomegranate Dye*

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Original Article

1. INTRODUCTION

In the present scenario, where there is an insatiable need for energy, solar energy has become a new ray of hope, that could, if utilized in a proper way, can lead the world towards a more sustainable, reliable and safe form of energy. Hence, the field of solar is shining bright with the ideas of researchers in and around the globe whose insights have paved way for a brighter future [1]. The hurdle in the effective utilization of solar energy thus far is mainly the cost factor [2]. It is reported that energy generation through the available silicon-based photovoltaic devices is nearly ten times costlier than the energy produced through conventional fossil fuels [3]. Thus, there is a severe lack of unanimous acceptance of the conventional silicon solar cells for practical applications. But, the ever shrinking limited non-renewable resources, strict government regulations calling to reduce the CO_2 emissions have once again put the utilization of renewable energy sources in the lime-light. Solar photovoltaics has been identified as a promising solution to satiate the energy requirements and is considered to be the primary component that would contribute to the

future energy generation on the global scale [4]. Thus, there is now a greater impetus on reducing the cost of energy generation through renewable sources such as solar energy and make it more attractive for its widespread acceptance and use. The first-generation photovoltaic solar cells made out of either crystalline silicon (c-Si) or gallium-arsenic (GaAs) wafers, though technologically advanced, lack efficiency at higher temperatures and are not economical from the point of view of production and material costs. This led to the development of thin-film solar cells, aptly termed as 'second generation solar cells'. These cells are cost-effective as these can be produced economically through smaller usage of energy [5]. But, these cells lack efficiencies [6]. Hence, to overcome these limitations, the field of photovoltaics has come up with 'third generation solar cells' which aim at producing low-cost and highly efficient solar cells. Dye Sensitized Solar Cells (DSSCs), belong to third generation solar cells, which is gaining popularity and finding practical applications in the various fields [7]. DSSCs become attractive because they are made with materials that are economical and the fabrication procedure does not require elaborate manufacturing technologies, thus making these cells are fairly cheap compared to the conventional silicon cells [8]. The dye used in the DSSCs is organic and impart the cells with pleasing colors, rendering these cells as an aesthetic advantage over the conventional silicon cells. In order to increase the commercial viability of DSSCs, focused research needs to be advanced in exploring different materials that can enhance the operating credibility of DSSCs.

The current work focuses on the construction of dye sensitized solar cells (DSSC) with variation in coating materials of the anode part of the cell. Most commonly, Titanium dioxide is the primary material that is coated onto the anode part of the cell. The present work experiments with different D-group elements such as Titanium dioxide (TiO_2), Manganese dioxide (MnO_2) and Chromium trioxide (CrO_3), as the coating material that would absorb the dye. Different dyes such as those extracted from Spinach, Black Grapes and Pomegranate are used as light absorbing dyes and the efficiency of these dyes to convert light into electricity is studied. Current dye sensitized cell technology focuses on the use of Iodide solution as an electrolyte. The liquid electrolyte has the problem of seeping out of the cell and thus reducing the life of the cell. The current work studies the use of solid electrolyte such as Sodium Chloride crystals and the effect of the same on the efficiency of the cell.

2. STRUCTURE AND WORKING PRINCIPLE OF A DSSC

A typical DSSC is a sandwich structure consisting of an anode top layer, followed by an organic dye layer and a bottom layer made up of a suitable cathode. The anode material should possess an excellent optical and electrical conductivity that should not only absorb the incident solar radiation, but also should conduct the same to the subsequent dye layer. Researchers have come up with a various different materials that possess such properties. Examples include single-layer graphene [9], nanocomposites of TiO_2-graphene [10], TiO_2-carbon nanotubes [11], ZnO-carbon fiber [12], Nb_2O_5 nano-assemblies [13], zinc doped barium strontium titanate [14] and many such innovative materials where the primary characteristics include photoconductivity, porous structure with good physical properties. The second layer of the DSSC is made up of an organic dye which is covalently bonded to the porous layer at the back of anode. The primary function of the dye is to generate photo-excited electrons through the effective absorption of the solar radiation coming in through the photo anode. These two layers are then covered by a conducting opposite electrode whose side facing the dye is coated with an iodide electrolyte which is a typical redox couple which stabilizes the dye by converting to triiodide. The triiodide is once again restored back to iodide from the electron flowing back through the external load. The conducting opposite electrode is usually a transparent glass which is made conductive through the coating of platinum or carbon. Figure 1 illustrates the basic structure of the DSSC.

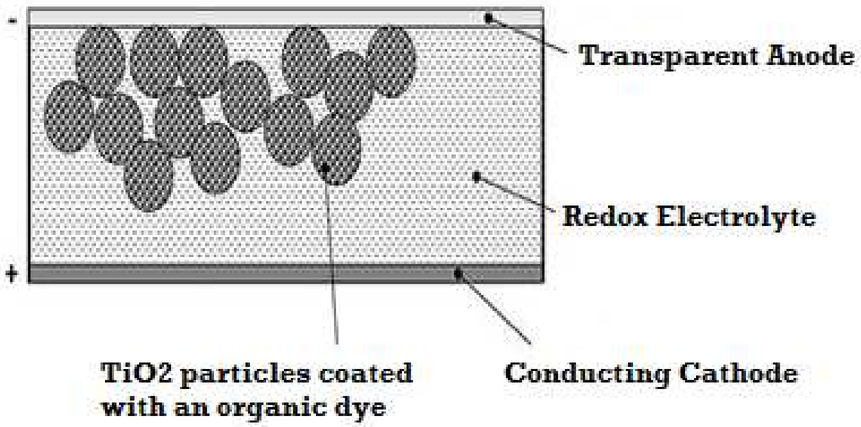

Figure 1: Structure of a DSSC.

Photons strike the dye soaked TiO_2 layer when the incident solar radiation passes through the transparent anode. This photoexcitation of the dye molecule bring about the ejection of an electron which is passed into the conduction band of TiO_2. This electron then moves to the transparent anode through diffusion and moves towards the cathode through the external load. The electron deficient dye will now acquire its lost electron from the redox iodide electrolyte which is in turn oxidized to triiodide. Triiodide is once again reduced back to iodide through the recombination of triiodide molecule with the electron at the cathode surface which has travelled from the anode through the external load. Thus, a cycle is setup which ensures the movement of electron within the loop. This electron movement generates the electricity. The working principle of a DSSC is depicted in the figure 2.

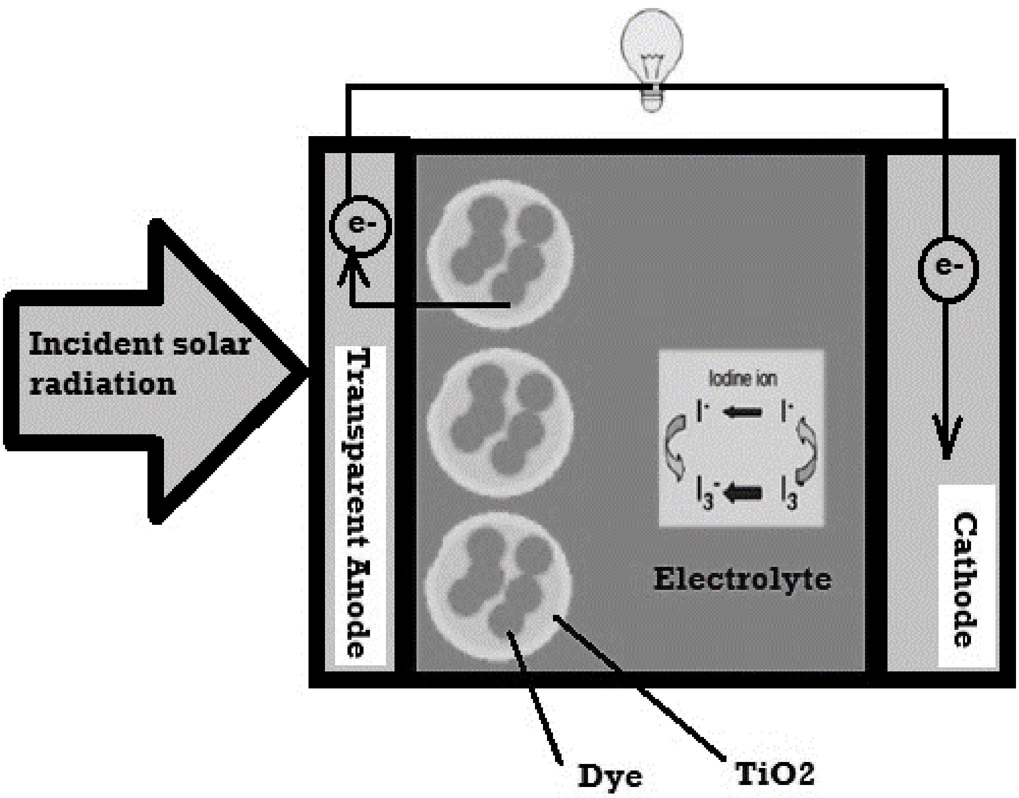

Figure 2: Working Principle of a DSSC.

3. MATERIAL SELECTION

3.1. Coating Materials for the Anode of a DSSC

The important characteristic required for the coating material for the anode of a DDSC is that it should be highly conductive, should possess excellent solar radiation absorbability and should be porous in nature to absorb and accommodate the dye pigments. TiO_2 remains the most widely used anode coating material in the production of DSSC. TiO_2 has an extremely porous structure and is an excellent UV absorber. It is known to convert effectively the harmful UV light into heat. Anatase form of TiO_2 is an excellent photocatalyst and it is also documented that TiO_2 in combination of nitrogen or when doped with metal oxides, exhibits superior photocatalytic activity when exposed to light [15]. An effort is made in the present work to evaluate the different oxide powders that have been sintered to form the second layer beneath the anode. In the present work, Manganese and Chromium (in their oxide forms), which share their places with Titanium in the D-group of the periodic table, have been chosen and experimented upon, as the materials that absorb the dye. Manganese dioxide and Chromium trioxide are used as the dye absorbing materials, alongside the conventional Titanium dioxide, to form a highly porous layer which, effectively and efficiently absorbs the dye. Manganese dioxide (MnO_2) coupled with TiO_2 is used as coating for anode in DSSC and is found to be effective photo conductor [16]. Chromium trioxide (CrO_3) is an excellent oxidative agent and is stable when mixed with organic solvents [17].

3.2. Organic Dye Pigments

Organic dye pigments are used in DSSCs in both their natural as well as their synthetic forms. Natural organic dyes are attracting the attention of the research community as they are found to be an effective alternative to the expensive synthetic dyes with ease of availability, low cost and environment-friendly [18]. Natural organic dyes render DSSC to harvest sunlight by mimicking the photosynthesis activity performed by the natural dye pigments. The bright yellow, orange and red colors produced by many plants are due to carotenoid pigments. These pigments help the plant to absorb visible light and aid in photosynthesis where the chlorophyll present in the plant has a lower capacity to absorb light. Carotenoids also protect the plant cell membranes by effectively blocking the harmful UV radiation. Flavonoids are another group of organic elements found in plant tissue that aid in light absorption required for photosynthesis. Some of these flavonoids have the ability to absorb light in the visible spectrum and thus qualify as pigments with colors depending on the wavelength of the light absorbed and reflected. These flavonoid pigment molecules are made up of a loosely bond outer electron which can be easily photo-excited. This characteristic is important to qualify as a dye sensitizer used in a DSSC. In the present work, natural dyes extracted from spinach, grape and pomegranate are used as dye sensitizers.

3.3. Electrolyte Material

The main function of the electrolyte in a DSSC is dye regeneration through the donation of an electron from the electrolyte to the dye. The electrolyte used in DSSC should be stable over a long period without disintegrating. Thus, the electrolyte should be highly resistant to thermal, chemical, photo and electrochemical degradation. This in turn will ensure the effective, efficient and reliable performance of the dye coupled to the oxide coated anode. Iodide is the most commonly used redox electrolyte in the DSSC. Aqueous iodide salt solutions are the preferred choice for electrolyte due to the formation of triiodide as given in equation (1).

$$I^- + I_2 \rightleftharpoons I_3^- \quad (1)$$

However, iodide electrolytes are severely corrosive in nature which greatly hamper the life of sealants and metallic elements used in a DSSC. This causes problems in the assembly of a DSSC and also reduces the life of the cell [19]. Another cause of concern with the use of liquid iodide electrolyte is the problem of retaining it in the required space for a long operating period. It is generally found that liquid electrolyte seeps out easily between the slides resulting in a faster degradation of the dye and in turn render DSSC with short operating life. To overcome this problem, in the present work solid fused salt crystals are used as a redox electrolyte.

4. CONSTRUCTION OF THE CELL

First, the construction of the conventional DSSC that uses Titanium dioxide as the dye absorbing material has been carried out. Titanium dioxide powder is diluted with vinegar and grinded to a fine paste in a mortar and pestle. This paste is then applied onto a clean glass slide, leaving a 2–3 mm gap on one side. This step was followed by sintering of TiO_2 layer which helps in reducing its resistivity. Sintering was carried out by heating the TiO_2 coated anode in an electric furnace preheated to a temperature of 450°C and holding it for about 20–25 minutes. The anode is then allowed to reach room temperature. A layer of carbon black is coated on one side of the cathode glass slide. The dye (juice of Spinach/pomegranate/back grapes) is then poured on the cooled titanium dioxide coated slide and allowed to rest for some time so that the dye gets completely absorbed by the titanium dioxide layer. The iodide electrolyte solution is then poured over the dye soaked TiO_2 layer. Next, the carbon-black deposited cathode slide is placed face down on top of the electrolyte such that the clear sides on either slides are opposite to one other. Figure 3 illustrates the arrangement of anode and cathode slides for the fabrication of DSSC.

The cell is clipped with the help of a binder clip. The multimeter is then attached to the cell with the help of the alligator clips, to measure the voltage output. Figure 4 depicts the final clipped DSSC. The cells with the layer of Manganese dioxide and Chromium trioxide are fabricated in the similar fashion. Another set of DSSCs are fabricated by applying fused salt electrolyte in place of iodide electrolyte.

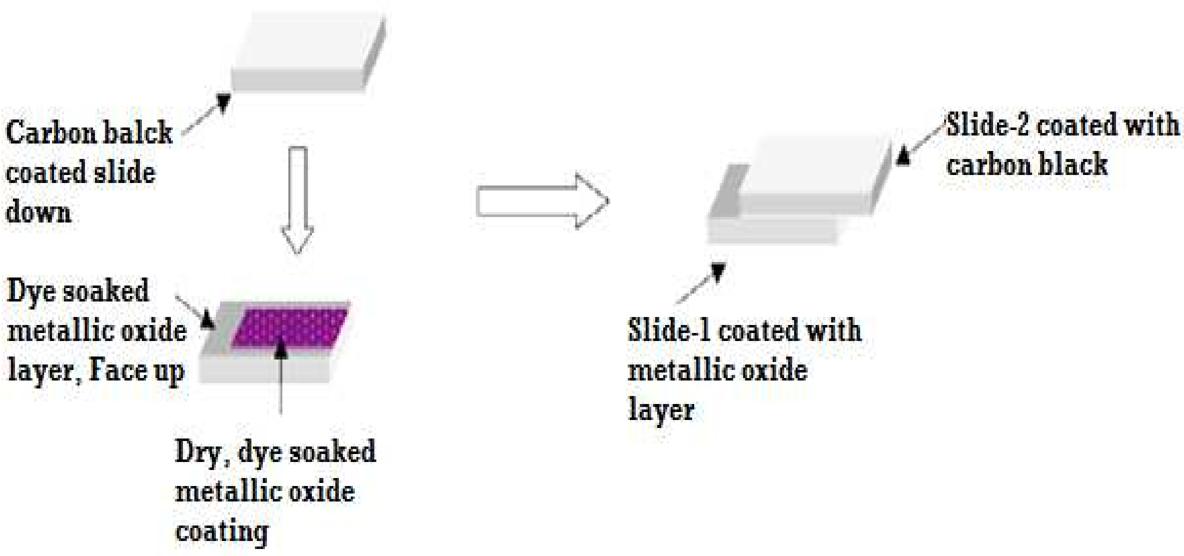

Figure 3: Orientation of Cathode and Anode Slides in a DSSC.

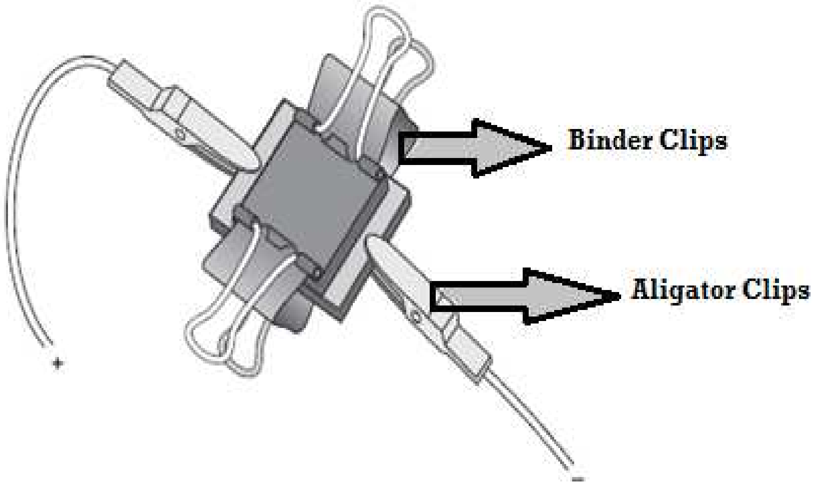

Figure 4: Clipped DSSC.

5. CODING OF DSSC

The fabricated DSSCs were coded for convenience and for easy recognition. Table 1 illustrates the coding of DSSC carried out in the present work.

Table 1: Coding for Fabricated DSSCs

Sl No.	Anode Coating	Dye	Electrolyte	Code given	Group Number
1	Titanium Dioxide	Spinach	Iodide	DSSC1	Group 1
2	Titanium Dioxide	Spinach	Sodium Chloride	DSSC2	
3	Titanium Dioxide	Black Grapes	Iodide	DSSC3	
4	Titanium Dioxide	Black Grapes	Sodium Chloride	DSSC4	
5	Titanium Dioxide	Pomegranate	Iodide	DSSC5	
6	Titanium Dioxide	Pomegranate	Sodium Chloride	DSSC6	
7	Manganese Dioxide	Spinach	Iodide	DSSC7	Group 2
8	Manganese Dioxide	Spinach	Sodium Chloride	DSSC8	
9	Manganese Dioxide	Black Grapes	Iodide	DSSC9	
10	Manganese Dioxide	Black Grapes	Sodium Chloride	DSSC10	
11	Manganese Dioxide	Pomegranate	Iodide	DSSC11	
12	Manganese Dioxide	Pomegranate	Sodium Chloride	DSSC12	
13	Chromium Trioxide	Spinach	Iodide	DSSC13	Group 3
14	Chromium Trioxide	Spinach	Sodium Chloride	DSSC14	
15	Chromium Trioxide	Black Grapes	Iodide	DSSC15	
16	Chromium Trioxide	Black Grapes	Sodium Chloride	DSSC16	
17	Chromium Trioxide	Pomegranate	Iodide	DSSC17	
18	Chromium Trioxide	Pomegranate	Sodium Chloride	DSSC18	

6. TESTING AND EVALUATION

The dye sensitized solar cells coded DSSC1, DSSC 2, DSSC3, DSSC4, DSSC5 and DSSC6 were exposed to direct sunlight for a period of around five hours on a sunny bright day. The output of the cell in terms of voltage was measured at a time interval of 30 minutes and the readings are tabulated and plotted. In the current work, the fabricated solar cells were exposed to sunlight for a particular length of time (from 10.00 AM to 2.30 PM) and the voltage was measured using a multimeter. The selection of this duration of time is based on the fact that during these times the solar radiation can be captured to a maximum extent. The variation in the voltage with respect to time was studied and noted down.

7. RESULTS AND DISCUSSIONS

The voltage generated by the fabricated DSSCs was measured with the help of a calibrated multimeter. Figures 5, 6 and 7 illustrate the voltage characteristics for group 1 DSSCs. Similarly, figures 8, 9 and 10 depict the voltage characteristics for group 2 DSSC, while figures 11, 12 and 13 show the voltage characteristics for group 3 DSSC.

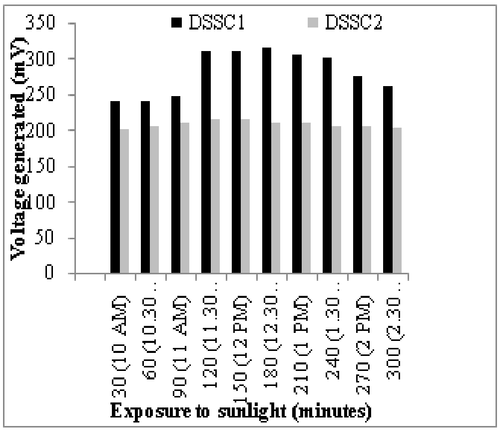

Figure 5: Voltage Characteristics for DSSC1 and DSSC2.

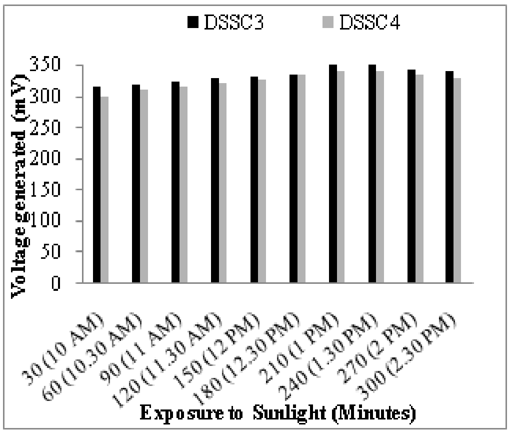

Figure 6: Voltage Characteristics for DSSC3 and DSSC4.

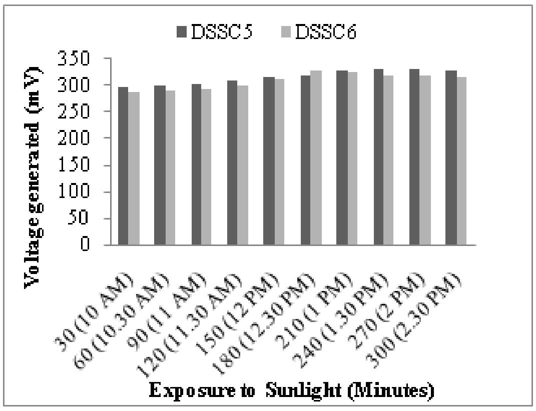

Figure 7: Voltage Characteristics for DSSC5 and DSSC6.

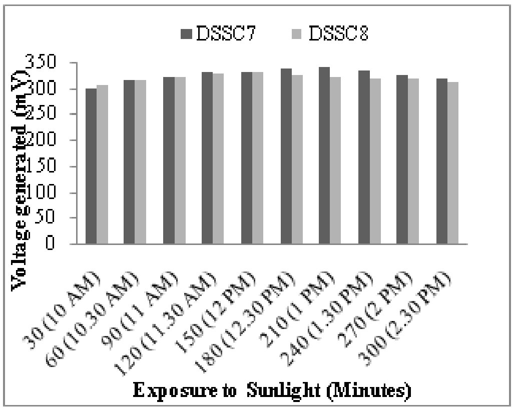

Figure 8: Voltage Characteristics for DSSC7 and DSSC8.

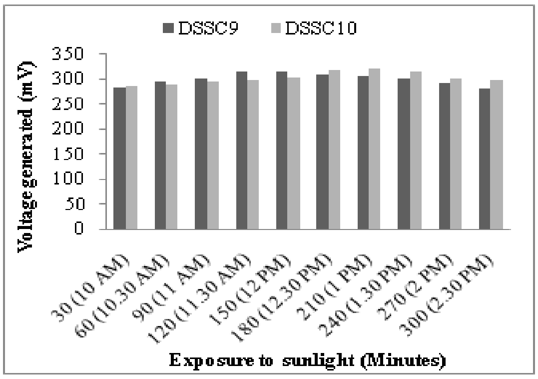

Figure 9: Voltage Characteristics for DSSC9 and DSSC10.

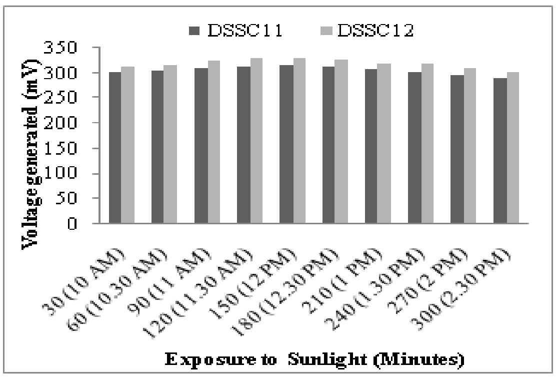

Figure 10: Voltage Characteristics for DSSC11 and DSSC12.

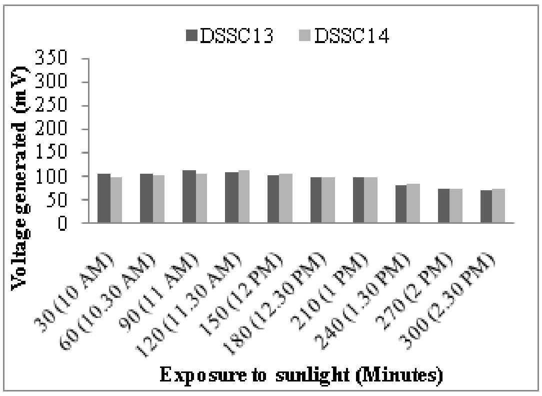

Figure 11: Voltage Characteristics for DSSC13 and DSSC14.

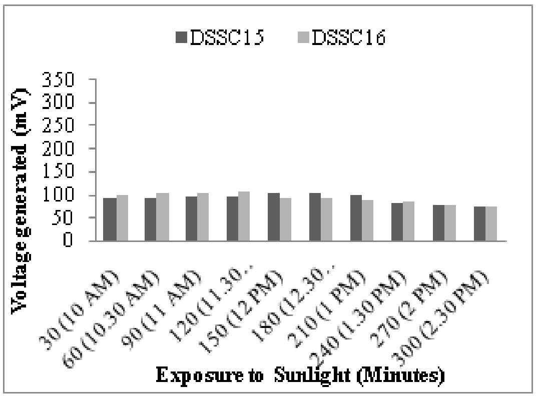

Figure 12: Voltage Characteristics for DSSC15 and DSSC16.

Analysis of the obtained results indicate that the cell having titanium dioxide as anode coating, spinach as dye and fused salt crystals as electrolyte (DSSC2) is generating higher voltage for the time length of exposure to sunlight as compared to the cell having titanium dioxide as anode coating, spinach as dye and Iodide solution as electrolyte (DSSC1). The results infer that a solid electrolyte shows good response compared to liquid electrolyte and thus overcoming the disadvantage of the liquid electrolyte which used to seep out from the cell and hence reducing the efficiency of the cell. On the other hand, the cell having titanium dioxide as anode coating, black grapes as dye and Iodide Solution as electrolyte (DSSC3) is showing better response as compared to the same cell with fused salt crystals as electrolyte (DSSC4). The result above contradicts the result obtained from DSSC1 and DSSC2 where the cell with solid electrolyte performed better. This deviation is due to the nature and components of the black grapes that react well with liquid iodide electrolyte as compared to solid sodium chloride electrolyte. From Figure 7 we can come to a conclusion that the cell having titanium dioxide as anode coating, pomegranate as dye and Iodide Solution as electrolyte (DSSC5) is generating the voltage consistently with the length of time compared to the same cell with fused salt as electrolyte (DSSC6). Thus, one can infer that pigments derived out of fruits having red and orange tinge perform better with TiO_2 coated anode and iodide as electrolyte. However, green tinged dye such as spinach dye, perform better with TiO_2 coated anode and solid fused salt electrolyte.

For group 2 DSSCs, it is observed that DSSC7 is performing better than DSSC8. But, there is no great variation in the voltage generated for a particular length of time of exposure to sunlight, for both DSSC7 and DSSC8. Hence, for the cell with manganese dioxide as the coating material for anode, spinach as dye, we can use fused salt crystals as electrolyte rather than iodide solution, and thus ensuring a stable electrolyte which will stay longer in its place and would simultaneously ensure a better performance of the solar cell over a length of time

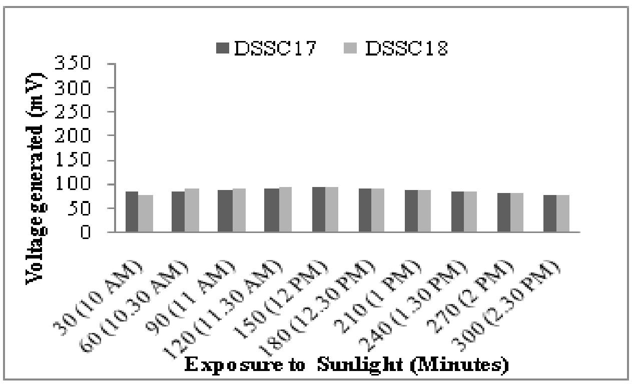

Figure 13: Voltage Characteristics for DSSC17 and DSSC18.

Figures 9 and 10 indicate that the DSSC with MnO_2 as anode coating, grape and pomegranate juice as dye respectively, and fused salt as electrolyte are generating much higher voltage compared to the same cells with iodide as electrolyte.

Figures 11, 12 and 13 indicate that the voltage generated by the solar cells DSSC13, DSSC14, DSSC15, DSSC16, DSSC17 and DSSC18 are more or less same without any greater variation. But the results clearly tell that the voltage generated by the DSSC with CrO_3 coated anode generates far less voltage as compared to DSSCs in group 1 and group 2. Thus, CrO_3 used as a coating material for anode fails to compete against TiO_2, as it disintegrates at a faster rate and reacts with the electrolyte quickly. Also, grinding the CrO_3 flakes into nano-size is also a very difficult task which reduces the surface area of absorption of the dye, thereby making the cell less efficient.

The voltage characteristics of the fabricated DSSCs illustrate that the DSSC with the dye absorbing material as Manganese Dioxide exhibited good response at par with the most tried and tested dye absorbing material such as Titanium dioxide. On the other hand, the DSSC with the dye absorbing material as Chromium Trioxide seems far less stable as it disintegrates quickly with the time length of exposure to sunlight, and thus rendering chromium trioxide a huge drawback for its use as a dye absorbing material in a DSSC. Also it can be seen that the DSSCs with spinach dye generates greater voltage followed by grape dye and then by the pomegranate dye. This shows that the dark colored organic dyes have greater photoexcitation level as compared to light colored dyes.

8. CONCLUSIONS

The field of photovoltaics is vast and the area of dye sensitized solar cells is very interesting and promising. In the present work it was to investigate with other D-group elements other than the conventional titanium dioxide. In this regard, manganese dioxide exhibits same qualities as that of titanium dioxide. Whereas, chromium trioxide fails miserably at this point, due to its high reactivity with electrolytic materials that was used. Darker and deep colored vegetables and/or fruits such as spinach and black grapes were found to perform better than the dye obtained from light colored dyes such as pomegranate. The major drawback of the dye sensitized solar cell is that it has a lot of liquid elements such as iodide electrolyte and keeping this liquid electrolyte in its place is of major concern. In the current work, use of sodium chloride crystals as an electrolyte was promoted and it performed considerably effectively, thereby solving the problem of liquid electrolyte. Use of conducting glass slide is advised instead of a plain non conducting glass slide. There is also a need to find out ways that would replenish the fast exhausting dye with time as dye is the heart of a dye sensitized solar cell.

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